

Verification facility for cryogenic optics, mechanisms, and structures for the SIRTf telescope

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ABSTRACT

NASA's Space Infrared Telescope Facility (SIRTf) is a 1-meter class cryogenically-cooled space observatory. The constituent sub-assemblies are currently in their assembly and verification phase. To facilitate the assembly and verification of the telescope, the Space Telescope Test Facility (STTF) has been built at the Jet Propulsion Laboratory (JPL). The STTF allows for the assembly, alignment, and optical characterization of individual components, as well as the telescope assembly with its cryogenic mechanism, at temperatures from 300 to 5 K in a chamber with interior diameter of 1.4 m, and a height of 2.3 m. The chamber is surrounded by a class 10,000 or better clean room. This paper reports on the functional and operational capabilities of this facility.

Keywords: Cryogenic optics testing, SIRTf, infrared

1. INTRODUCTION

The SIRTf Telescope Test Facility was built in 1994¹ for cryogenic interferometer testing of the prototype optical components for the SIRTf telescope. It is one of the few 4 K optical dewars capable of testing meter sized mirrors, and the only one capable of doing so in the vertical orientation. In 1995² active testing of the prototype primary mirror began, and a prototype telescope test was performed in the fall of 1997³. After these tests it was decided to upgrade the facility for testing of the Flight Telescope. These upgrades fell into two basic categories: 1) due to a design change in the telescope focal length additional optical measurement capability was needed; and 2) to meet the Flight cleanliness requirements many changes were required with the most significant being the construction of a Class 10,000 cleanroom. All of these modifications will be discussed in the text along with a general overview of the facility. Another unique feature of the STTF is its cost of operation compared to other facilities. Staffing during Flight Hardware testing has run at 4.5 full time employees while during prototype testing only 2 full time employees were used. Currently, this unique facility is in the final stages of testing the SIRTf telescope and will be available for general use in the fall of 2000.

2. OVERVIEW OF STTF DEWAR

As shown in Figure 1, the STTF dewar consists of three coaxial shells. The inner shell is cooled to liquid helium temperatures, the middle shell to liquid nitrogen temperatures, while the outer shell is for vacuum. The inner helium shell is formed by a 300 liter lower helium tank to which a 1.4 meter diameter aluminum cylinder (helium shroud) is mounted. A second 300 liter tank is mounted inside the helium shroud at either a position of 1.5 or 2.3 meters above the lower tank surface depending on whether a mirror or telescope test is being performed. Other positions could be accommodated with minor modifications. 2.3 meters is the maximum distance between the two tanks. For a telescope test, the telescope is mounted to the lower tank, while an optical flat is mounted to the upper tank. When the primary mirror is tested, it is

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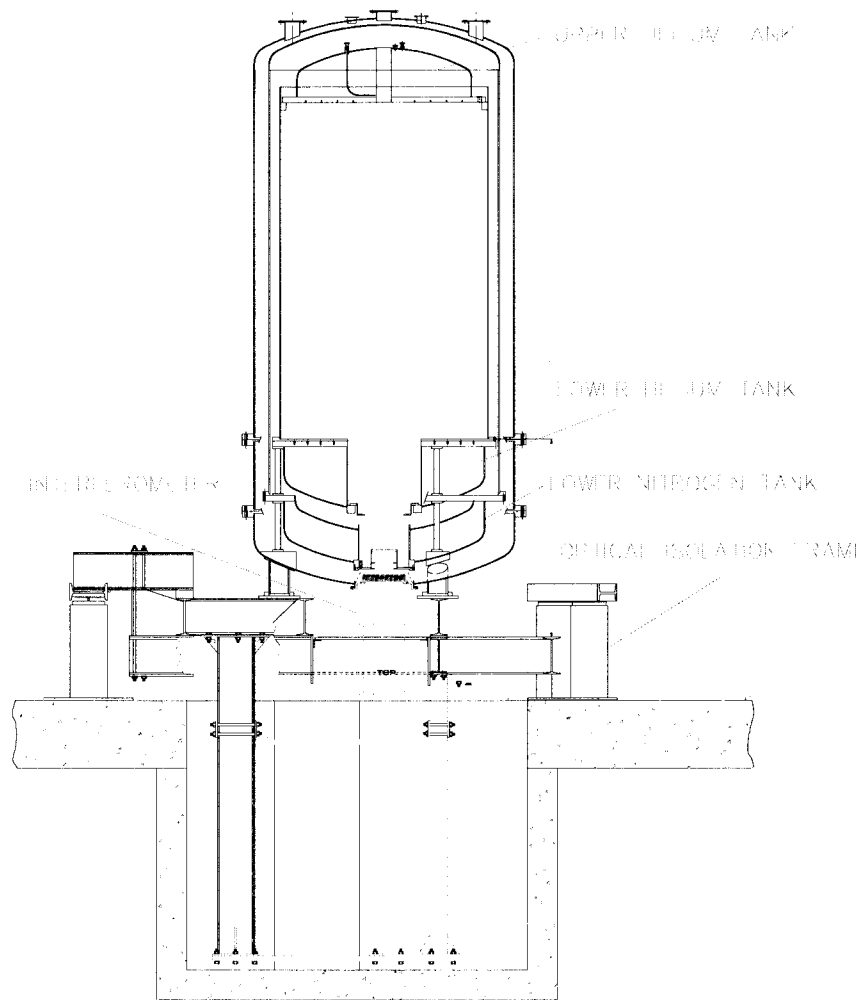


Figure 1: Drawing of STTF dewar mount on dewar isolation frame. Also shown is the 6 foot pit and new orientation for the interferometer as discussed in the text.

mounted to the upper tank. The maximum volume for optical test pieces is given by the 1.4 m cylinder diameter and the 2.3 meter distance between tanks. All of the outer surfaces of the two helium tanks and the aluminum cylinder are covered with three layers of MLI to decrease the emissivity to 0.01 at liquid helium temperatures. The lower helium tank is annular shaped with a 20 inch axial bore for various optical paths. When both of these tanks contain helium, the maximum temperature is 5 K seen at the mid point of the helium shroud. This temperature is independent of the helium levels in the tanks. The nitrogen shell is formed by a single tank mounted below the lower helium tank and a domed shroud (nitrogen shroud). The nitrogen tank and shroud are covered with 20 layers of MLI to intercept the large radiative heat load from room temperature. During nominal operations the temperature of the nitrogen shroud is 90 K. The nitrogen tank has a 17" diameter axial hole for the optical light path.

Below the nitrogen tank is a flange mount for an optical window. For the prototype testing we used a 2.75" diameter window, while the Flight hardware testing a 10" window is used. This window was part of the Flight upgrades and it allows the full SIRTf telescope focal plane to be probed. To reduce the heat leak through the window, baffling that does not obstruct the desired light cone can be added. For example, the SIRTf primary mirror light cone is large as it passes through the helium tank and converges to the window, while for the SIRTf telescope the light cone is largest as it leaves the chamber.

The chamber has a liquid nitrogen cooled shutter that with baffling reduces the heat leak to 20 mW at 4 K. With the shutter open the heat leak is about 40 mW. To help reduce the radiative heat leak the window was coated with gold. The radiative heat leak must be removed by the coupling between the dewar and the test optic or the test article cannot be guaranteed to reach 4 K. In all of our testing, OFHC braided straps were used to couple the dewar to the test optics.

Fill and vent lines from the two inner helium tanks penetrate the nitrogen shell as do two actuator rods for the gimbal mechanism of the top tank. The outer shell encloses the entire dewar and provides a 10^{-6} and 10^{-8} Torr vacuum at 77 K and 4 K respectively. Wiring feedthroughs penetrate the chamber with 40 resistance thermometers currently dedicated for the test optics with the capability of installing up to 100. Pressure sensors monitor the chamber vacuum. All of these sensors are recorded and displayed by Labview software. The heat load to the two helium tanks is about 6 W to each tank. This results in a hold time for the two tanks of 30 hours. For Flight hardware testing at 4 K, the facility is staffed 24 hours a day. When operations are at 77 K the facility is monitored by alarm limits in the data acquisition software. During prototype testing this was done for helium testing also.

3. OPTICAL OVERVIEW OF THE FACILITY

As shown in Figure 1, the window, tank bores, and the interior volume determine the size of test optic that can be tested. The facility is capable of testing meter diameter optics up to an f of 3 and for 1/2 meter optics up to an f of 12. The ultimate limiting factor is the 10" window. The entire dewar is mounted on a triangular vibration isolation frame. This frame is supported by Newport pneumatic isolators which allows the dewar and test optics to float together. The isolators provide up to 40 dB attenuation of floor vibrations from 5 to 20 Hz. The degree of isolation is sufficient to permit interferometry measurements to be made during normal working hours. In order to measure the entire Flight SIRTf telescope focal plane, the old interferometer setup had to be modified. Previously, the interferometer lay horizontal relative to the dewar and a fold mirror was used to pass the light into the dewar. Because the focal plane had moved closer to the dewar optical window it was no longer feasible to use a fold mirror. It was decided to mount the interferometer on axis with the light path of the dewar. To do this a 6 foot pit, shown in Figure 1, was excavated below the dewar and an additional I-beam structure was attached to the existing isolation frame. A mounting table, which can be moved to any vertical position below the dewar window, was part of this new structure. The new structure is stiff enough that interferograms of the same quality as before the modification are obtained. Finally, 5 axis optical stages were used to mount the interferometer to the isolation frame. These stages can be driven remotely which proved invaluable when mapping the telescope focal plane.

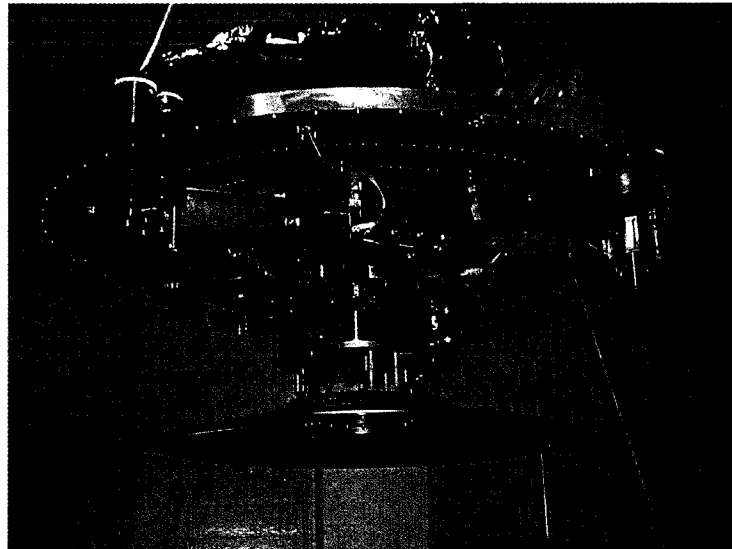


Figure 2: SIRTf primary mirror attach to two axis cryogenic tip-tilt gimbal. At the left is the new lead screw. Visible is the bi-pod flexure and the brass housing for the ball screw as discussed in the text.

For coarse alignment, a two axis optical gimbal mechanism for alignment is attached to the upper helium tank. It is shown in Figure 2 with the SIRTf primary mirror attached to it. The design of this gimbal has been discussed previously⁴. In addition to primary mirror testing, an optical test flat is attached to the gimbal mechanism during testing of the SIRTf telescope. The gimbal mechanism is a triangular aluminum frame pivoting on a monobearing which is driven in tip tilt by cold lead screws which can be actuated while the system is cold. Flexures decouple the test piece from the gimbal to prevent stress to the optic from differential cooling. Originally tungsten di-sulfide lubricated lead screws were used. In order to handle the larger load of a new test flat, these lead screws were replaced with non-lubricated ball screws. These lead screws have performed well throughout our current testing. The entire tank and gimbal hardware can safely handle 50 kg test pieces.

The telescope is bolted to the upper surface of the lower helium tank through G-10 blocks which provide thermal isolation between the tank and telescope. OFHC straps are used to provide a calculable level of cooling to the telescope. The tank surface is machined with T-slots which allow for attachment at any radial position on the tank. Figure 3 shows the SIRTf telescope mounted to the lower helium tank of the STTF.

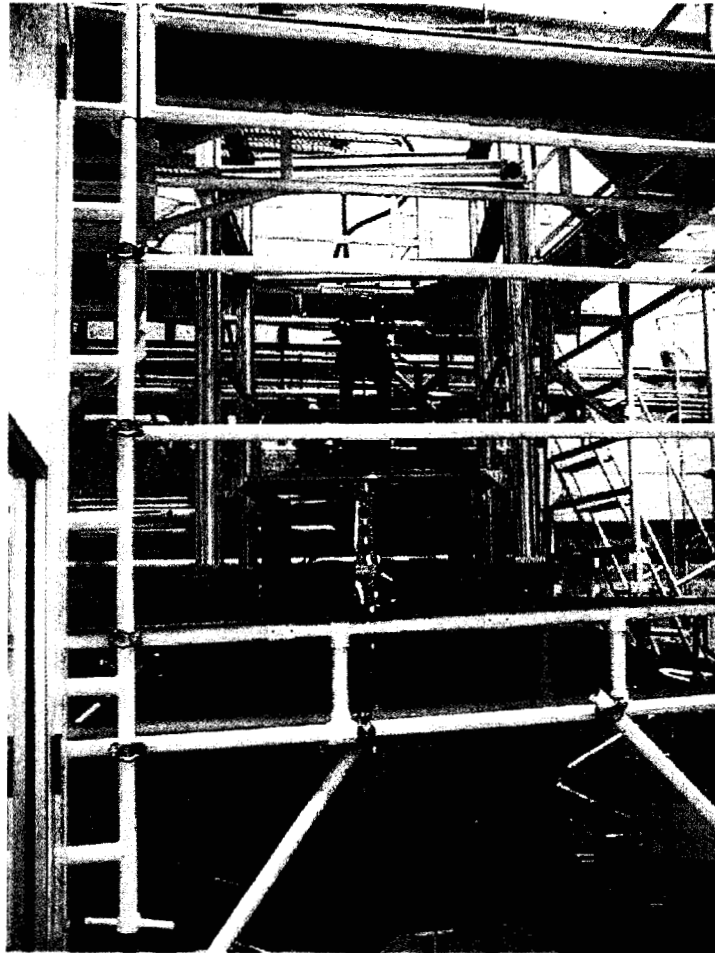


Figure 3: SIRTf telescope mounted to lower helium tank. Picture shows the two level scaffold and the optical isolation frame. The interferometer is visible below the vacuum shell.

4. ADDITIONAL INFRASTRUCTURE

To meet the Flight cleanliness requirements various modifications to the facility were made. The most important was the construction of a 10,000 class clean room. Because of space constraints, an ante room was constructed which served as a class 100,000 environment where the data acquisition and optical measurements are made. In addition, the roof of this room serves as a storage area for the large shrouds and the helium storage dewars are placed here when transfers are performed. To

prevent chamber contamination an oil free turbomolecular system was obtained as part of our upgrades. A relay latched valve safeguards the chamber vacuum if power is lost. For rough vacuum a Roots blower external to the laboratory was installed. Surrounding the dewar is a 2 level scaffold that allows integration of optics to the lower tank and assembly of the dewar (see Figure 3). The facility is equipped with a 2.5 Ton bridge crane. An optical table is available for alignment work. Also, the laboratory is plumbed with supply lines for both gaseous and liquid nitrogen.

5. FACILITY OPERATION

To cool the dewar and optics the chamber is first pumped to a vacuum of 10^{-4} Torr. This typically takes from 1-2 days depending on how long the MLI on the shrouds has been exposed to air. The three tanks are filled with liquid nitrogen which takes about 8-10 hours. The dewar itself will cool to liquid nitrogen temperature in 1 day. For our SIRTf testing, the cooldown to 77 K of the optics took 3 days for both the prototype mirror and telescope. For the Flight mirror and telescope the cooldown times were 9 days. During cooldown, interferometer data is taken at various temperatures. This data has provided important information on the thermal cycling behavior of the SIRTf telescope materials and its construction. In order to obtain stable interferograms the cleanroom HEPA filters, the air conditioning, and chamber pump must be turned off. This can be done for long periods of time (routinely done for 8 hours) with no adverse effects. When the test optics has equilibrated at 77 K, more data is taken. The nitrogen is then removed from the two helium tanks and liquid helium is transferred. Dewar cooldown time to 4K is about 2 hours. Again the cooldown time for the optics will depend on the particular test article. For the SIRTf prototype testing cooldown of the test optic to 4 K was four hours. For the Flight optics the time is 7 days. The cooldown time is determined essentially by the test optic and the allowable gradients that it can support on cooling. In the SIRTf testing, a switch to titanium flexures decreased the thermal coupling between the dewar and the test piece. After data is taken at 4 K, warming of the dewar begins. All cryogens are first removed from the three tanks with a helium gas purge. When all the helium surfaces have reached the nitrogen triple point, the 3 tanks are purged with GN₂. If data is needed again at 77 K the tanks are refilled with LN₂. At this point, 50 mTorr of exchange gas is added to the chamber to aid in the warmup. The exchange gas also serves to reduce the temperature difference between the test optics and the dewar. The test optics reach 200 K in approximately 36 hours. The dewar is not opened until the test optics are above the ambient dew point. For prototype testing an entire liquid helium test cycle would take four weeks. For the current SIRTf Flight testing the helium cycle time is 8 weeks.

6. SUMMARY

The Jet Propulsion Laboratory's Space Telescope Test Facility (STTF) is a proven low cost 4 Kelvin cryogenic optics facility. It is capable of testing 1 meter class optics in the vertical orientation. It has been upgraded for the special requirements of Flight Hardware testing with the two main upgrades being enhanced optical capability and a 10,000 class cleanroom in which all operations are carried out. For prototype testing it was operated by two full time employees while for Flight testing 4.5 full time employees were needed. This level of staffing is much less than any comparable facility. The STTF is in the last phases of its SIRTf testing and will be ready for other users in the fall of 2000.

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